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ADVANCED FUEL SYSTEMS FOR RAMJET-POWERED VEHICLES

Contract F33615-69-C-1849

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Air Force Aero Propulsion Laboratory

Wright-Patterson Air Force Base, Ohio 45433

attn: ARPA.

Prepared by

Atlantic Research Corporation
A Division of The Susquehanna Corporation
Alexandria, Virginia

(11) 9 Mar[redacted]70

(12) 13p.

Prepared by: Donald H. Sargent

(10) Donald H. Sargent
Principal Investigator

Approved by: Kermit E. Woodcock

Kermit E. Woodcock
Program Manager

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1.0 SUMMARY

The major efforts during this reporting period were in determining the low-temperature mechanical properties of bladder and seal materials, in obtaining additional permeability data for bladder materials, and in fabricating the fuel system simulator.

Although Viton and the Viton/Nomex composite elastomers became stiff at -65°F, they did not become brittle. The Viton/Nomex construction (US 941) retained half the elongation at -65°F as compared to room temperature. Based upon these results, this material remains the primary choice for the bladder. The Nitrile/Nylon construction (US 566 RL) exhibited greater flexibility, and will be the backup material.

Permeability data was obtained using much larger elastomer surface area test specimens than previously used. The measured permeability rates of Shelidyne H through Viton, through Viton/Nomex, and through Nitrile/Nylon were all extremely low, less than 0.05 $mg/cm^2/day$.

Fabrication of the fuel system simulator proceeded satisfactorily. The supporting skids were completed, most of the purchased components have been delivered, and the fuel tank assemblies and the first fuel bladders are in work.

2.0 LOW-TEMPERATURE MECHANICAL PROPERTIES

Since the fuel system simulator must perform its delivery function at -65°F, the elastomers used for the bladder material and for seals must not embrittle at -65°F, and must retain sufficient flexibility to function in an acceptable manner.

Nitrile rubber is a copolymer of butadiene and acrylonitrile. As the acrylonitrile content is decreased, the low-temperature flexibility of the rubber is increased, but at the expense of resistance to oils and fuels and to elevated temperatures. With proper compounding, nitrile rubber retains sufficient flexibility at -65°F so that it is commonly used for this low temperature service*.

Silicone rubber possesses excellent resistance to temperature extremes. Flexibility has been demonstrated at -175°F, and the normal maximum service temperature for sustained periods is 500°F. Fluorosilicone elastomers have

* Parker Seal Company

flexibility at -65° and are resistant to many fuels and oils.* However, the silicones and fluorosilicones have much poorer tensile strengths than other elastomers, it is difficult to effectively reinforce these rubbers because of poor adhesion properties, and permeability rates are high.

Viton has outstanding resistance to fuels and oils, and is useful to extremely high temperatures. Its low-temperature properties are not as attractive as those of some other elastomers, but Viton, through proper compounding and component design, can be used at -65°F.

Time-honored flexibility tests of O-rings indicate a minimum usable temperature of -40 to -50°F for Viton. However, these tests are based on the ease of flexing over a given size mandrel. Most elastomers become hard and brittle and break and shatter in the flexing test when they reach their minimum usable temperature. Viton merely becomes stiff. Tests at -65°F conducted by F. H. Pollard of Republic Aviation Corp. (SAE Journal, May 1959) resulted in successful sealing by Viton.

General Dynamics concluded that F-111 wing cavity fuel cells made of Viton materials were good for severe flexing and wrinkling in the -35°F to -40°F range and for moderate flexing at -65°F.

Teflon, in addition to its inert character, possesses excellent low- and high-temperature mechanical properties. The main drawbacks are cold flow, the necessity for using thin sections to achieve flexibility, relatively poor tear resistance, the difficulty in fabrication and bonding, and high cost.

Ethylene propylene terpolymer (EPT) has good low-temperature flexibility, but it is basically incompatible with hydrocarbons.

In order to document the low-temperature mechanical properties of the specific materials under study in this program, a series of low-temperature tests were conducted on US 941 (Viton/Nomex construction), US 566 RL (Nitrile/Nylon construction), US 3094 (unreinforced Viton), US 3015 (unreinforced EPT), and Teflon (TFE). The first was a qualitative test of immersing a strip of material in a dry ice-MEK bath and attempting to bend the strip 180° upon itself. At -35°F, the Nitrile/Nylon and the Teflon performed successfully, but the EPT, the Viton and the Viton/Nomex cracked. At -65°F, all five materials were bent double without cracking.

* Parker Seal Company

Quantitative tensile tests were performed on these materials as a function of temperature. Table 2.1 lists the data obtained for US 3094 (unreinforced Viton) and for US 3015 (unreinforced EPT); Table 2.2 lists the data for US 941 (Viton/Nomex) and for US 566 RL (Nitrile/Nylon); and Table 2.3 lists data interpolated from values published by the DuPont Company for Teflon (TFE). In addition to the measured rupture stress and rupture strain, Tables 2.1, 2.2, and 2.3 list the rupture stress reduced to an arbitrary 73°F reference temperature according to Smith*:

$$\text{Reduced Rupture Stress} = \frac{T_o}{T} \times \text{Rupture Stress}$$

where T = test temperature, °R

T_o = reference temperature = 533 °R.

The rupture stress is shown as a function of temperature in Figure 2.1, and the rupture strain is shown as a function of temperature in Figure 2.2. Figure 2.2 shows that both ethylene propylene terpolymer (EPT) and Teflon retain well over 100 per cent elongation at -65°F, confirming the qualitative bending test previously discussed. Unreinforced Viton loses elongation rapidly at lower temperatures, but there is still 30 per cent elongation at -65°F. This data confirms the fact that Viton stiffens but does not embrittle at this temperature. The Viton/Nomex composite suffers a sharp drop in elongation below -45°F, but there still is almost half the elongation at -65°F that the material has at room temperature. The one point for the Nitrile/Nylon composite confirms the fact that this construction is much more flexible than the Viton/Nomex construction at -65°F.

The reduced rupture stress plotted against rupture strain in Figure 2.3 defines a Smith Failure Envelope for each material. Any combination of stress and strain to the right of each curve results in a failure of the material. Hence, failure will be averted if the component design limits the strain at a particular stress to the left of the curve.

The conclusion drawn from these data is that Viton and Viton/Nomex have limited flexibility at -65°F, but that these materials are not totally brittle so that they could be useful in the proper configuration. Teflon, Nitrile rubber, and EPT have greater flexibility than Viton at -65°F.

* T. L. Smith, "Ultimate Tensile Properties of Elastomers. II. Comparison of Failure Envelopes for Unfilled Vulcanizates", J. Applied Physics **35** 1, 27-35 (Jan. 1964).

TABLE 2.1

Tensile Properties of Unreinforced Materials at Varying Temperatures.

Test Temperature (°F)	US 3094 (Viton) Rupture Stress (psi)	US 3094 (Viton) Rupture Stress Reduced to 73°F (psi)	US 3094 (Viton) Rupture Strain (percent)	US 3015 (EPT) Rupture Stress (psi)	US 3015 (EPT) Rupture Stress Reduced to 73°F (psi)	US 3015 (EPT) Rupture Strain (percent)
165	492	420	471	488	416	401
	474	404	466	422	360	403
Average	483	412	468	455	388	402
73	1,588	1,588	698	1,807	1,807	685
	1,535	1,535	690	1,807	1,807	687
	1,508	1,508	732	1,692	1,692	608
Average	1,544	1,544	707	1,769	1,769	660
0	2,928	3,399	403	2,451	2,846	495
	2,631	3,055	364	2,381	2,764	480
Average	2,780	3,227	364	2,416	2,805	488
-20	3,510	4,258	231	2,783	3,376	444
	3,506	4,253	260	2,605	3,160	423
Average	3,508	4,256	246	2,694	3,268	434
-45	3,686	4,744	86	2,824	3,634	330
	3,455	4,447	109	2,647	3,407	319
Average	3,570	4,596	98	2,736	3,520	324
-65	3,782	5,113	24	2,950	3,988	288
	3,760	5,084	35	2,993	4,047	240
Average	3,776	5,098	30	2,972	4,018	264

TABLE 2.2

Tensile Properties of Reinforced Materials at Varying Temperatures.

Test Temperature (°F)	US 941 (Viton/Nomex) Rupture Stress (psi)	US 941 (Viton/Nomex) Rupture Stress Reduced to 73°F (psi)	US 941 (Viton/Nomex) Rupture Strain (percent)	US 566 RL (Nitrile/Nylon) Rupture Stress (psi)	US 566 RL (Nitrile/Nylon) Rupture Stress Reduced to 73°F (psi)	US 566 RL (Nitrile/Nylon) Rupture Strain (percent)
165	3,253	2,770	18			
	3,333	2,840	18			
	3.500	2,990	15			
Average	3,362	2,870	17			
73	4,395	4,395	14			
	4,124	4,124	17			
	4,244	4,244	17			
Average	4,254	4,254	16			
0	5,263	6,110	–			
	6,053	7,020	11			
	5,479	6,340	15			
Average	5,598	6,490	13			
-20	6,603	8,000	10			
	7,763	9,410	17			
Average	7,183	8,700	14			
-45	10,134	13,020	11			
	9,698	12,460	14			
	10,563	13,570	14			
Average	10,123	13,010	13			
-65	11,781	15,900	7	9,910	13,370	18
	10,875	14,670	7	10,910	14,710	17
	11,333	15,300	7	10,091	13,800	18
Average	11,329	15,300	7	10,304	13,900	18

TABLE 2.3

Tensile Properties of Teflon (TFE) at Varying Temperatures (Calculated from Data in December 1964 Issue of the Journal of Teflon).

Temperature (°F)	Rupture Stress (psi)	Rupture Stress Reduced to 73°F (psi)	Rupture Strain (percent)
165	2,870	2,450	367
73	3,600	3,600	282
0	4,230	4,900	230
-20	4,400	5,330	215
-45	4,620	5,940	198
-65	4,810	6,500	184

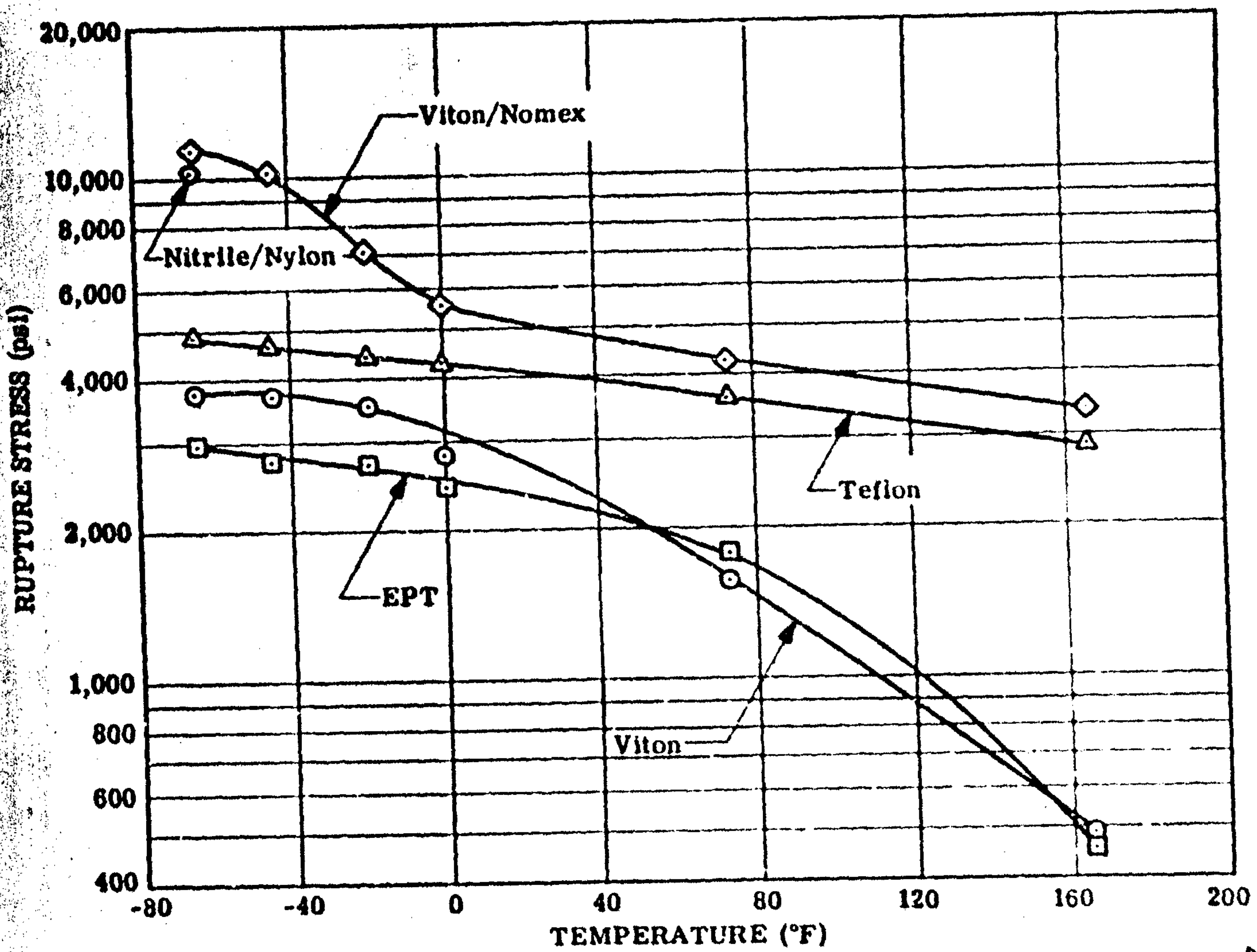

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Figure 2.1. Rupture Stress Versus Temperature.

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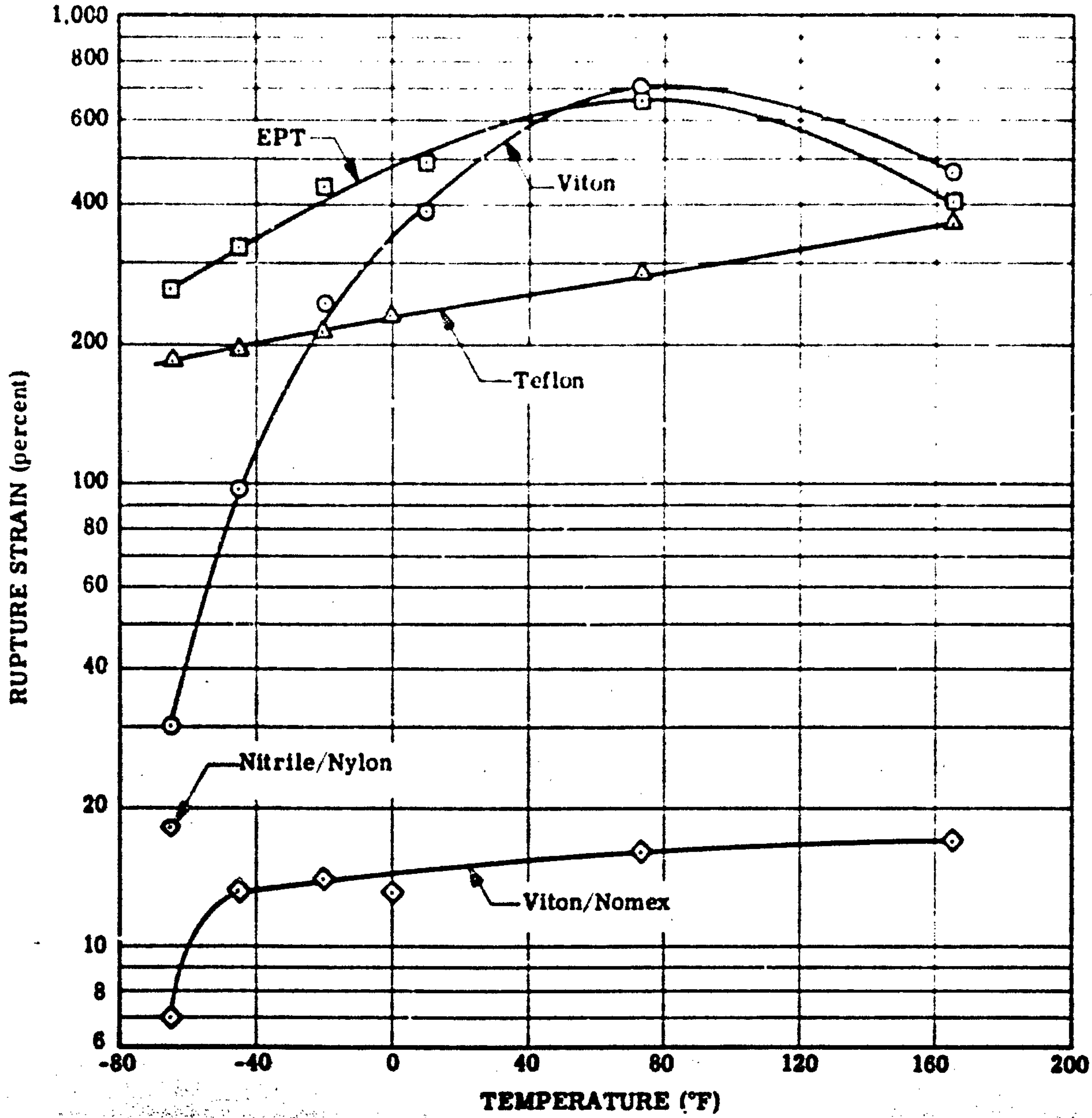

Figure 2.2. Rupture Strain Versus Temperature.

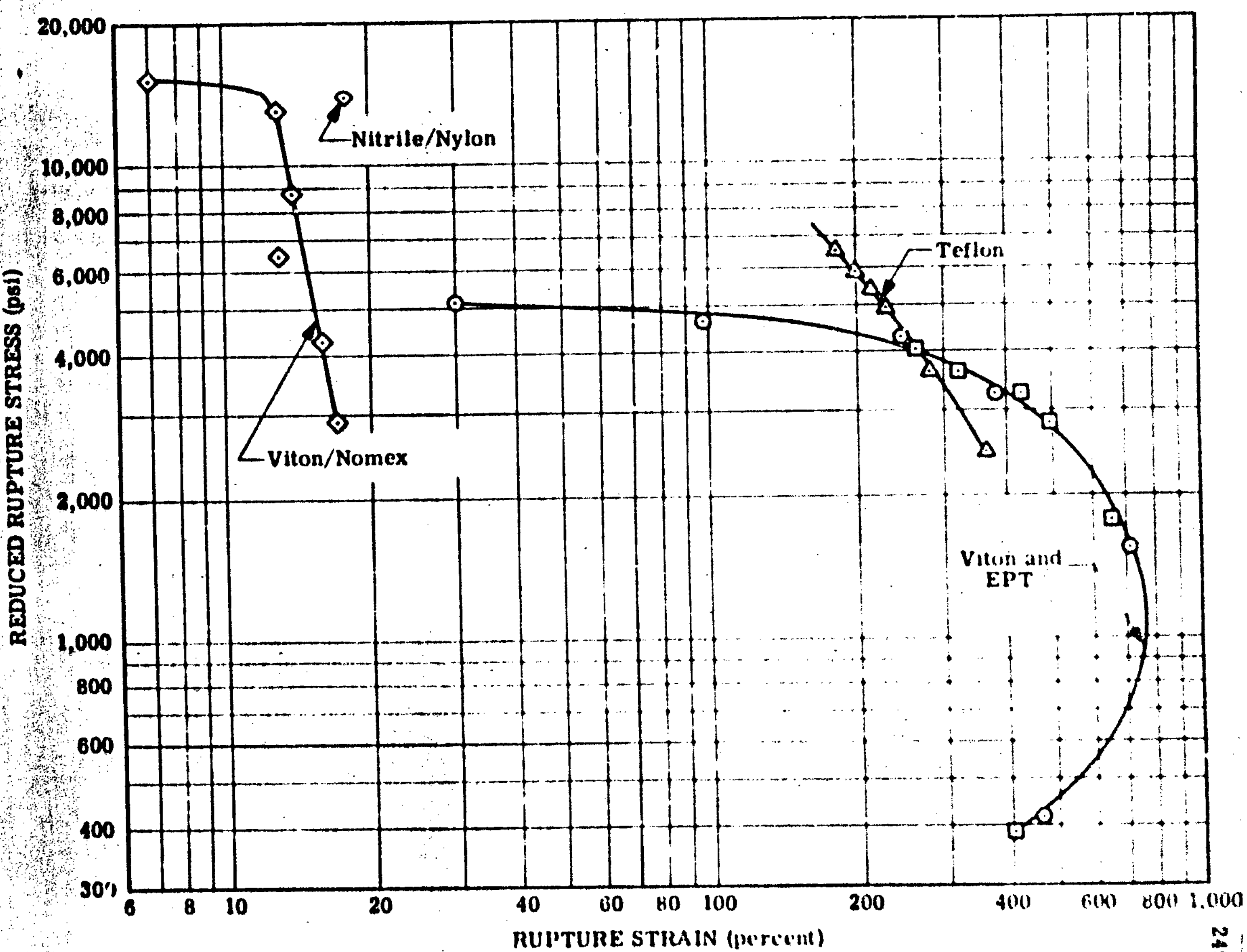

Figure 2.3. Failure Envelopes.

3.0 PERMEABILITY DATA

In order to gain more accurate data for the rates of Shelldyne H permeability through bladder materials, larger test specimens were prepared and placed in test February 9, 1970. Each test specimen consisted essentially of two 6-inch discs of elastomer bonded together at the outer edge, with a bond width of one inch, leaving a 4-inch diameter cavity. This cavity was filled with Shelldyne H and the specimen was sealed. Periodic weighings of each specimen is the measure of fuel permeability.

Seven specimens in all were prepared. There were two specimens of Viton (US 3094, 0.054 inches thick), two specimens of Viton/Nomex construction (US 941, 0.030 inches thick), and three specimens of Nitrile/Nylon construction (US 566 R, 0.032 inches thick). It should be noted that the Nitrile/Nylon construction used in these tests has thicker rubber layers than the US566 RL reported elsewhere, which had an overall thickness of 0.019 inches. However, for the purposes of measuring permeability rates, the nylon film barrier (which offers the controlling mass transfer resistance) is identical in the two constructions, so that the permeability data obtained is applicable to either construction.

The data obtained for the first 21 days is listed in Table 3.1. It is apparent that all of the permeability rates measured are extremely low.

4.0 FABRICATION OF FUEL SYSTEM SIMULATOR

During the past month, fabrication of the fuel system simulation was a major activity. The purchased components have either been received or are expected shortly, except for the turbine flowmeter which is due in April. The plexiglass fuel tank components are in work and due shortly, in sufficient time to begin checkout testing. The steel fuel tank is in work and is expected in April. Major components that have been received include the skid mountings and the catch tank.

During the past month, the initial order for two Viton/Nomex (US 941) fuel bladders was placed with Uniroyal, Inc. The design has been modified to provide six longitudinal reinforcing strips to promote the desired uniform folding configuration during fuel expulsion. Hangers will be provided on the forward end of the bladder to encourage longitudinal folding.

TABLE 3.1 PERMEABILITY RATES

(Rates are in milligrams/cm^2/24 hours)

Material	Specimen	Permeability Rate
Viton US 3094	1	0.051
	2	0.041
	Average	0.046
Viton/Nomex US 941	1	0.019
	2	0.027
	Average	0.023
Nitrile/Nylon US 566 R	1	0.030
	2	0.034
	3	0.017
	Average	0.027

A vacuum-jacketed heat exchanger built by General Applied Science Laboratories, for the Air Force under another program, will be used in this program for low-temperature conditioning of the fuel, in order to shorten the setup time for low-temperature testing.

5.0 WORK PLANNED FOR FOLLOWING PERIOD

The major effort will be concerned with the fabrication and installation of the fuel system simulator. Additional fuel bladders will be ordered, of the US 566 RL construction (Nitrile/Nylon).

Other efforts should include the continuation of long-term storability and compatibility testing, and the preparation of a fuel reprocessing system.

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